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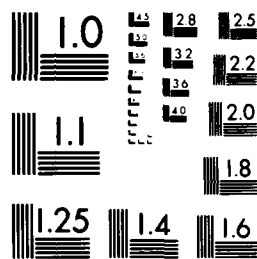
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# **CLEAN-BURNING DIESEL ENGINES — Phase III**

**INTERIM REPORT  
BFLRF No. 215**

By

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Prepared for

**Belvoir Fuels and Lubricants Research Facility (SwRI)  
Southwest Research Institute  
San Antonio, Texas**

Under Contract to

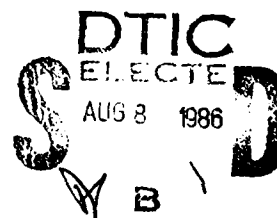
**U.S. Army Belvoir Research, Development  
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)  Gaseous and particulate emissions were measured from diesel forklift engines under a variety of steady-state conditions. An EPA certification fuel was used to determine CO, CO <sub>2</sub> , NO, HC, particulate, aldehydes, smoke and SO <sub>2</sub> emission rates from Isuzu C-240, Peugeot XD3P, and Teledyne TMD-20 diesel engines. Emission rates were reported in g/hp-hr, g/hr, and observed concentration, i.e., ppm, percent, or mg/m <sup>3</sup> .				
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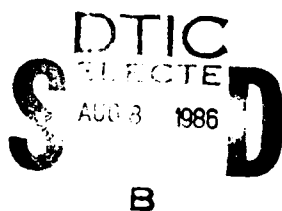
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## FOREWORD

Work Directive 18, "Clean Burning Diesel Engines," was issued on September 13, 1982 under Contract DAAK70-82-C-0001 to the U.S. Army Mobility Equipment Research and Development Command (MERADCOM; currently the Belvoir Research, Development and Engineering Center). Phase III of this work was initiated in March 1985 under Contract DAAK70-85-C-0007, Work Directive 23. The engineering and analytical efforts of this program were conducted by the Department of Emissions Research of Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78284. This program was identified within Southwest Research Institute as Project 02-8341-175.

This project was under the overall supervision of Harry E. Dietzmann, Manager of the Chemical Analysis Section. He was assisted by Dr. Lawrence R. Smith (chemical analysis) and Mr. Ernie Krueger (engine testing). Emission testing was initiated in July 1985 and was completed in December 1985. Mr. Tim Lee of Belvoir Research, Development and Engineering Center, STRBE-GMW, was the technical officer, Mr. James Stephens served as the overall program manager, and Mr. F. W. Schaekel, Belvoir Research, Development and Engineering Center, STRBE-VF, served as Contracting Officers Representative.



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## I. INTRODUCTION

The United States Army is investigating the possibility of replacing the currently used electric forklift with diesel engine-powered forklifts in handling hazardous materials. Electric-powered forklifts have no noise or air pollution problems, however, the logistic problems associated with field operations have prompted the U.S. Army to investigate other possible alternatives. The diesel engine has many advantages, i.e., mobility, cost, maintenance, however, the use of diesels in areas of limited ventilation is of concern.

This program is the third in a series of programs conducted to characterize gaseous, particulate, and unregulated emissions from diesel engines considered as potential candidates for forklift vehicles used to handle hazardous materials. The first program was conducted to characterize exhaust emissions from a Deutz F3L 912W engine and a Perkins 4.2032 engine operating on a MIL-F-46162A(MR) fuel.<sup>(1)\*</sup> The second program involved four diesel forklift engines, a Deutz F3L 912W, a Deutz F4L 912W, a Perkins 4.2032, and a Perkins 4.2482; two test fuels, MIL-F-46162B(ME) (a high sulfur reference fuel) and an EPA certification fuel (DF-2 emissions certification fuel); and included engine operation with selected induced faults.<sup>(2)</sup> This third study expands the emissions data base for potential diesel engine-powered forklifts to include three additional engines, an Isuzu C-240, a Teledyne TMD-20, and a Peugeot XD3P operating on an EPA certification fuel.

### A. Objective

The objective of this program was to expand the exhaust emissions characterization data base of diesel engines considered as potential candidates for forklift vehicles to include the emission characterization of three additional diesel-powered engines. This emission characterization was accomplished on engines provided by Belvoir R,D&E Center and included gaseous and particulate emissions of potential concern when these engines are operated in confined areas. The method used to evaluate these engines was the modal steady-state procedure used in the 13-mode Federal Test Procedure.<sup>(3)</sup>

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\*Numbers in parentheses designate references at the end of the report.

B. Scope

Three diesel forklift engines were provided by Belvoir R,D&E Center for this study, an Isuzu C-240, a Teledyne TMD-20, and a Peugeot XD3P. The test fuel was an EPA DF-2 certification fuel and was obtained from Phillips Petroleum Company. Emission characterization was accomplished over the test matrix in Table 1. Emission rates are presented in g (or mg)/hp-hr, g (or mg)/hr, and observed concentrations.

**TABLE 1. TEST MATRIX FOR EMISSION TESTING OF ISUZU C-240, TELEDYNE TMD-20, AND PEUGEOT XD3P DIESEL ENGINES USING EPA DF-2 CERTIFICATION FUEL (PHILLIPS DF-2 EMISSIONS FUEL)**

<u>Engine Speed</u>	<u>Engine Load</u>	<u>Emission Measurement</u>
Idle	--	Group I, II, III
Peak Torque	2%	Group I, II, III
Peak Torque	25%	Group I, II
Peak Torque	50%	Group I
Peak Torque	75%	Group I
Peak Torque	100%	Group I
Rated	2%	Group I, II
Rated	25%	Group I
Rated	50%	Group I, II
Rated	75%	Group I
Rated	100%	Group I, II, III

Group I - includes CO, CO<sub>2</sub>, HC, NO<sub>x</sub> (NO + NO<sub>2</sub>), Smoke  
Group II - includes particulates and SO<sub>2</sub>  
Group III - includes aldehydes

## II. DESCRIPTION OF FACILITIES, ENGINES, AND PROCEDURES

### A. Engine Description

This program involved emission mapping for gaseous, particulate, smoke, aldehydes, and sulfur dioxide emissions on three diesel forklift engines. The three diesel engines were tested using an EPA DF-2 emissions certification fuel. Engines in this study included an Isuzu C-240, Teledyne TMD-20, and a Peugeot XD3P. New engines were supplied by Belvoir R&D Center.

#### 1. Isuzu C-240

The first engine tested in this program was an Isuzu C-240 engine rated at 43 hp at 2400 rpm. This four-cylinder, water-cooled engine was delivered to Southwest Research Institute (SwRI) in April 1985. A performance map was accomplished on the engine upon receipt at SwRI and after an 80-hour engine break-in. The engine performance data, both before and after engine break-in, are presented in Table 2, and the engine break-in schedule is presented in Table 3. Views of the Isuzu C-240 on the test stand are illustrated in Figure 1.

Hydrocarbon emissions during the initial 13-mode emissions test on the Isuzu C-240 were unstable. Although the 13-mode was a valid test, the unsteady hydrocarbon emissions were of concern. As a result of these concerns, two additional 13-mode emission tests were conducted. The hydrocarbon emissions were stable during these tests, and these results were averaged for comparison purposes.

#### 2. Teledyne TMD-20

The Teledyne TMD-20 was supplied new by Belvoir R,D&E Center. This three-cylinder, water-cooled diesel engine was rated at 37.7 hp at 2230 rpm and underwent the 80-hour break-in schedule presented in Table 3. The engine performance data for the Teledyne TMD-20 before and after the 80-hour break-

TABLE 2. SUMMARY OF ENGINE PERFORMANCE TESTS BEFORE AND AFTER 80-HOUR ENGINE BREAK-IN ON ISUZU C-240, TELEDYNE TMD-20, AND PEUGEOT XD3P

Engine Speed, rpm	Isuzu C-240 <sup>a</sup>		Teledyne TMD-20 <sup>b</sup>		Peugeot XD3P <sup>c</sup>	
	Before 80-hr Break-in	After 80-hr Break-in	Before 80-hr Break-in	After 80-hr Break-in	Before 50-hr Break-in <sup>d</sup>	After 50-hr Break-in <sup>d</sup>
800	12.0	13.7	--	--	--	--
900	13.9	15.5	--	--	14.8	14.3
1000	15.8	17.3	16.0	15.9	17.2	16.7
1100	18.0	19.1	17.8	17.8	19.7	19.2
1200	20.0	21.3	19.6	19.6	22.4	21.5
1300	22.1	23.5	21.5	21.5	24.6	24.1
1400	23.6	26.1	23.5	23.5	27.3	26.6
1500	25.1	27.8	25.3	25.7	30.0	29.0
1600	26.8	29.8	27.2	27.7	32.8	31.6
1700	28.9	31.8	29.0	29.5	35.3	33.7
1800	30.7	34.4	30.6	31.2	37.4	35.9
1900	32.7	36.9	32.3	32.7	39.4	37.9
2000	34.8	38.7	33.9	34.7	41.3	39.8
2100	36.3	40.1	35.5	36.2	43.6	41.8
2200	37.6	41.4	37.0	37.5	45.5	43.7
2300	38.9	43.1	37.1	35.6	47.7	45.5
2400	41.1	44.7	--	--	--	--

<sup>a</sup>Rated HP = 43

Rated Speed = 2400 rpm

<sup>b</sup>Rated HP = 37.7

Rated Speed = 2300 rpm

<sup>c</sup>Rated HP = 47.5

Rated Speed = 2300

<sup>d</sup>Engine had already accumulated 30 hours of operation when received at SwRI.

TABLE 3. BREAK-IN SCHEDULE FOR ISUZU C-240 AND TELEDYNE TMD-20

Step	Time per Step	Total Time	Engine Speed, rpm		Load, %
			Isuzu C-240	Teledyne TMD-20	
1a	0:15 min	0:15	1000	1000	0
1b	0:15 min	0:30	1400	1400	20
1c	0:15 min	0:45	1600	1600	30
1d	0:15 min	1:00	2000	2000	30
1e	0:15 min	1:15	2200	2100	50
1f	0:15 min	1:30	2400	2230	50
1g	0:15 min	1:45	2400	2230	75
1h	0:15 min	2:00	2400	2230	100
2	1:00	3:00	2000	2000	30
3	1:00	4:00	2200	2100	50
4	1:00	5:00	2400	2230	50
7	7 hours cycling time (total time 12:00 hours)	0:05	1200	1200	0
		0:25	1600	1600	60
		0:05	1200	1200	0
		0:25	1800	1800	60
8	8 hours cycling time (total time 20:00 hours)	0:05	1600	1600	0
		0:25	1200	1200	70
		0:05	1600	1600	0
		0:25	2000	2000	70
9	10 hours cycling time (total time 30:00 hours)	0:05	1600	1600	80
		0:25	2000	2000	80
		0:05	1800	1800	80
		0:25	2200	2230	80
10	10 hours cycling time (total time 40:00 hours)	0:15	1800	1800	90
		0:15	2200	2100	90
		0:15	2000	2000	90
		0:15	2400	2230	90

Repeat entire sequence to give a total of 80 hours

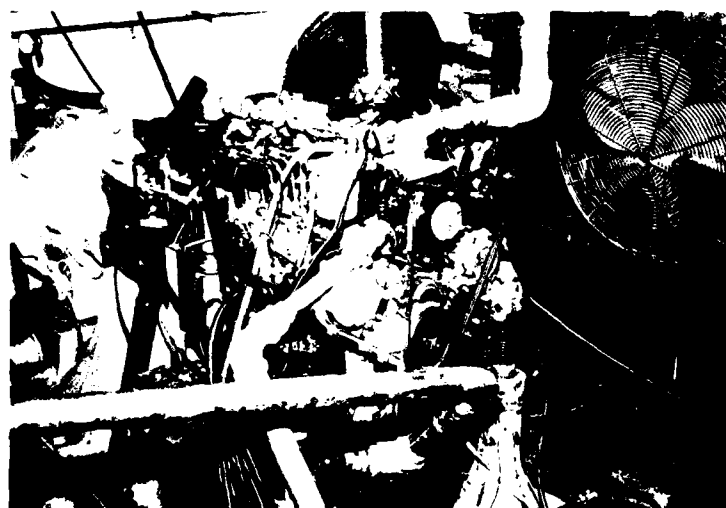
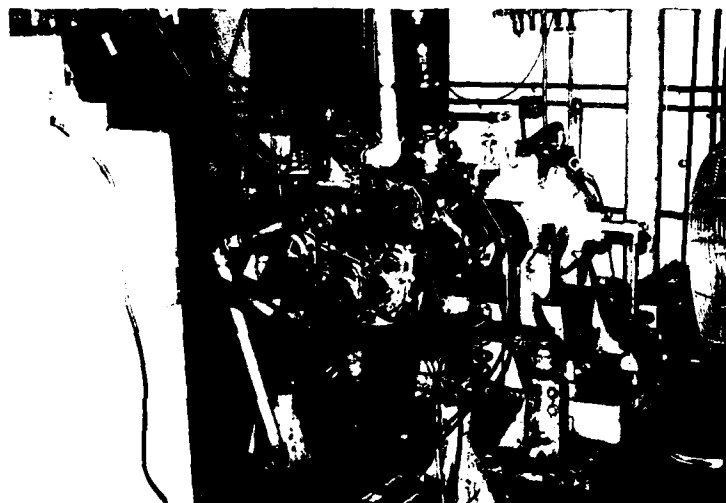


FIGURE 1. VIEWS OF ISUZU C-240 ON THE TEST STAND

in are illustrated in Table 2. Figure 2 illustrates the Teledyne TMD-20 on the test stand.

### 3. Peugeot XD3P

The Peugeot XD3P, a four-cylinder, water-cooled engine had already undergone 30 hours of operation when received at SwRI. This engine was rated at 47.5 hp at 2300 rpm. Since the engine had already accumulated 30 hours of operation, only 50 additional hours of engine break-in were conducted on the engine. This modified break-in schedule is presented in Table 4. The engine performance data for the Peugeot XD3P before and after the abbreviated engine break-in are illustrated in Figure 2. Figure 3 illustrates the Peugeot XD3P on the test stand.

#### B. Fuel Description

All testing in this program was conducted using EM-627-F, an EPA DF-2 certification fuel. This fuel met EPA certification specifications and was obtained from Phillips Petroleum Company. The fuel inspection data on the test fuel are presented in Table 5.

#### C. Dynamometer Description

A 250-hp Midwest wet gap eddy current dynamometer determined the load on the three test engines. Fuel was measured using a Flotron. An 8-inch stainless steel dilution tunnel was used to collect particulate samples. All equipment was calibrated prior to testing using accepted applicable procedures, i.e., Federal Register, SAE, EPA Recommended Practice, etc. Several views of the test equipment are illustrated in Figure 4.

#### D. Gaseous Emissions (Group I)

The measurement of gaseous emissions was accomplished using analytical equipment, procedures, and calculations specified in the Federal Register<sup>(3)</sup> for 13-mode certification testing. The specific analytical instruments used in this



FIGURE 2. VIEWS OF TELEDYNE TMD-20 ON THE TEST STAND

TABLE 4. BREAK-IN SCHEDULE FOR PEUGEOT XD3P

Step	Time per Step	Total Time	RPM	% Power	Load, lbs
1	10 hours cycling time (total time 40:00 hours)	0:05	1800	90	74.9
		0:25	2200	90	74.5
		0:05	2000	90	74.3
		0:25	2300	90	74.7
2	1:00	41:00	1600	30	24.6
3	1:00	42:00	1600	50	41.0
4	1:00	43:00	1800	30	24.9
5	1:00	44:00	1800	50	41.6
6	1:00	45:00	1800	80	66.6
7	7 hours cycling time (total time 52:00 hours)	0:05	1200	0	0.0
		0:25	1600	60	49.2
		0:05	1200	0	0.0
		0:25	1800	60	49.9
8	8 hours cycling time (total time 60:00 hours)	0:05	1600	0	0.0
		0:25	1200	70	52.3
		0:05	1600	0	0.0
		0:25	2000	70	57.8
9	10 hours cycling time (total time 70:00 hours)	0:05	1600	80	65.6
		0:25	2000	80	66.1
		0:05	1800	80	66.6
		0:25	2200	80	66.2
10	10 hours cycling time (total time 80:00 hours)	0:05	1800	90	74.9
		0:25	2200	90	74.5
		0:05	2000	90	74.3
		0:25	2300	90	74.7

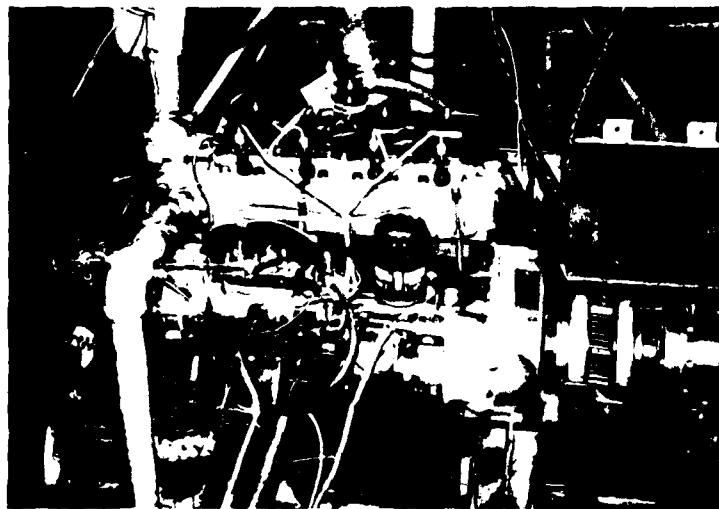
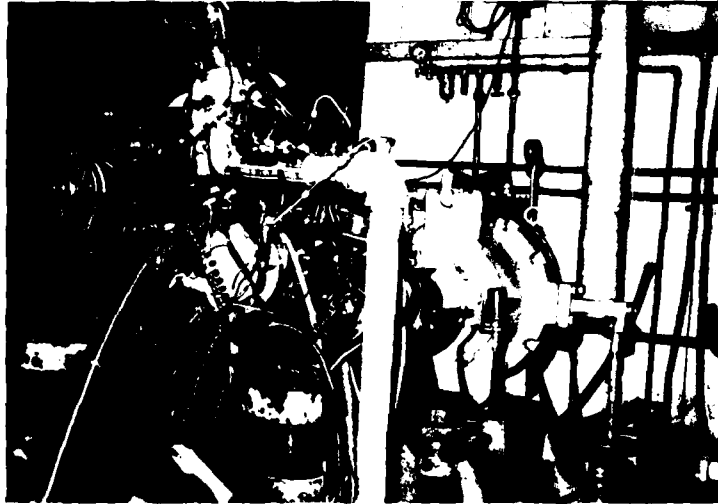
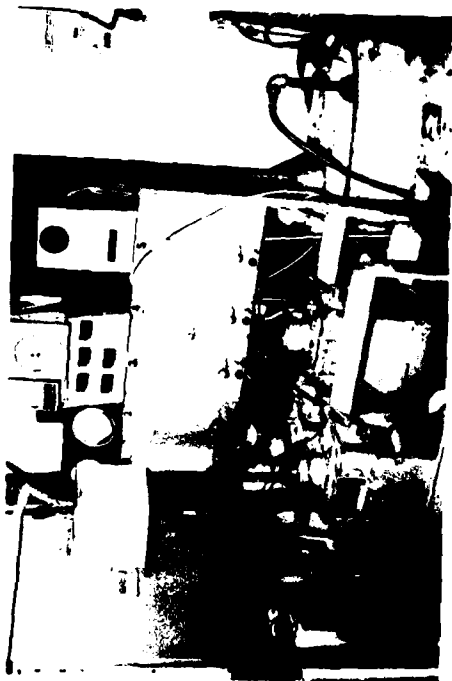


FIGURE 3. VIEWS OF PEUGEOT XD3P ON THE TEST STAND

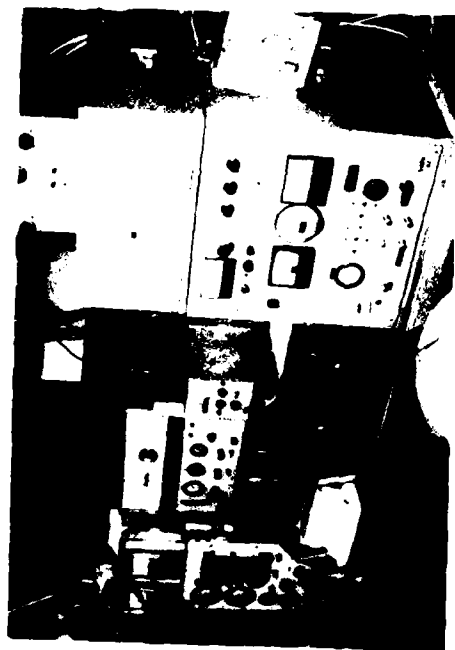
TABLE 5. FUEL INSPECTION DATA

<u>Fuel Property</u>	<u>Test Method</u>	<u>EPA Specifications</u>	<u>EM-627-F</u>
Cetane Number	D 613	42-50	46.2
Gravity, °API	D 287	33-37	35.2
Total Sulfur, Wt %	D 3120	0.2-0.5	0.35
Aromatics (FIA), Vol %	D 1319	27 min	32.1
Flash Point, °F (°C)	D 93	130 (54) min	162 (72)
Kinematic Viscosity, cSt	D 445	2.0-3.2	2.52
Particulate Matter	D 2276	NA <sup>a</sup>	2.1
Cloud Point, °F (°C)	D 2500	NA	+12 (-11)
Pour Point, °F (°C)	D 97	NA	0
Distillation Range, °F (°C)	D 86		
IBP		340-400 (149-204)	375 (191)
5% Recovered			415 (213)
10% Recovered		400-460 (204-238)	431 (222)
20% Recovered			451 (233)
30% Recovered			469 (243)
40% Recovered			487 (253)
50% Recovered		470-540 (243-282)	505 (263)
60% Recovered			523 (273)
70% Recovered			543 (284)
80% Recovered			567 (297)
90% Recovered		550-610 (288-321)	598 (314)
95% Recovered			628 (331)
EBP		580-660 (304-349)	653 (345)

<sup>a</sup>Not Applicable



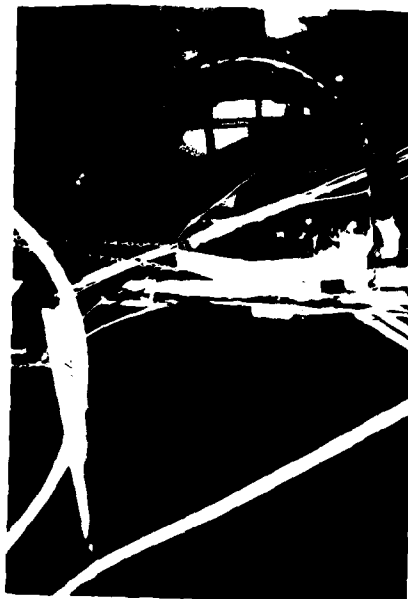
Particulate Sampling Controls



Gaseous Emissions Cart



Dilution Tunnel



Heated HC and NO<sub>x</sub> Interface

FIGURE 4. SEVERAL VIEWS OF GASEOUS AND PARTICULATE EMISSIONS INSTRUMENTATION

study are listed in Table 6, and several views of this equipment are also illustrated in Figure 4. A flow schematic of the gaseous emissions instrumentation is shown in Figure 5. One set of gaseous, particulate, and unregulated emissions instrumentation was used to obtain emissions data on this program.

**TABLE 6. LIST OF GROUP I EMISSION MEASUREMENT EQUIPMENT**

<u>Exhaust Species</u>	<u>Chemical Symbol</u>	<u>Detection Technique</u>	<u>Instrument</u>
Carbon Monoxide	CO	NDIR <sup>a</sup>	Beckman 315B
Carbon Dioxide	CO <sub>2</sub>	NDIR <sup>a</sup>	Beckman 315B
Oxides of Nitrogen	NO <sub>x</sub>	CL <sup>b</sup>	SwRI w/EPA Design
Hydrocarbons	HC	FID <sup>c</sup>	SwRI w/Beckman 402 Detector
Smoke	--	Opacity	PHS Smokemeter

<sup>a</sup>NDIR denotes nondispersive infrared

<sup>b</sup>CL denotes chemiluminescent analyzer

<sup>c</sup>FID denotes flame ionization detector

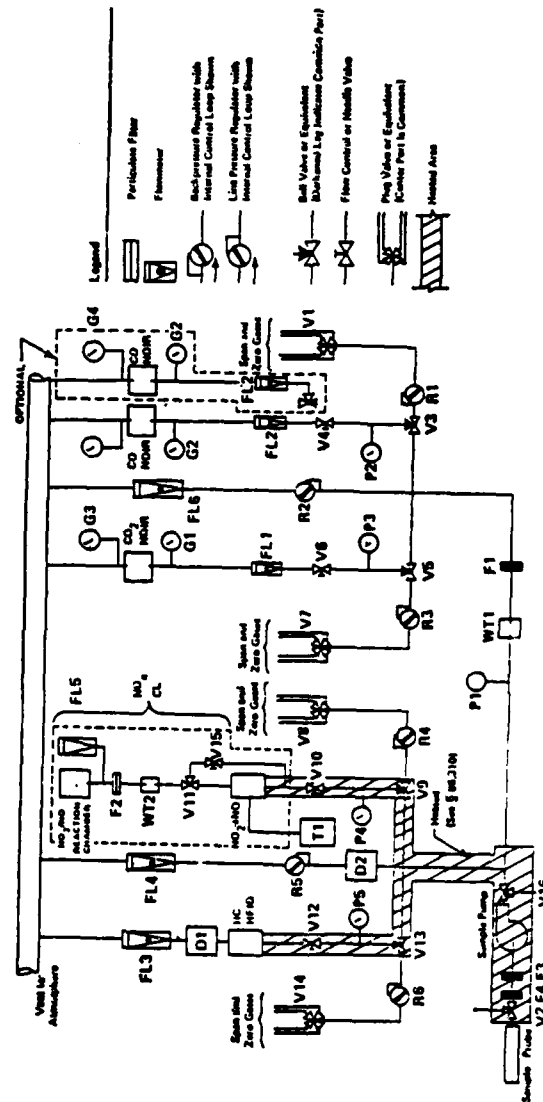


FIGURE 5. GASEOUS EMISSIONS CART FLOW SCHEMATIC

### III. ANALYTICAL PROCEDURES FOR UNREGULATED EMISSIONS

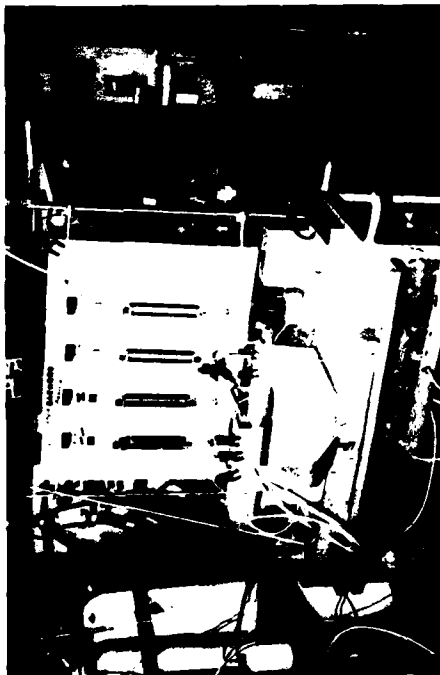
The analytical procedures used to measure the unregulated emissions are summarized in this section. Detailed descriptions of most of the procedures, along with discussions of their development, validation, and qualification, are available in Interim Report II, "Analytical Procedures for Characterizing Unregulated Pollutant Emissions From Motor Vehicles," developed in a related EPA project.<sup>(4)</sup> Several views of Group II and III sampling systems are shown in Figure 6.

#### A. Description of Analytical Procedures

The unregulated emissions evaluated in this project, along with the methods for sampling and the procedures used in the analyses, are listed in Table 7. Aldehydes and ketones represent a group of compounds. This procedure separates and identifies a number of individual components. The analytical procedures involved in this project are briefly described in the following subsections.

##### 1. Aldehydes and Ketones

The collection of aldehydes (formaldehyde, acetaldehyde, acrolein, propionaldehyde, crotonaldehyde, isobutyraldehyde, benzaldehyde, and hexanaldehyde) and ketones (acetone and methylethylketone) is accomplished by bubbling exhaust through glass impingers containing an acetonitrile solution of 2,4 dinitrophenylhydrazine (DNPH) and perchloric acid. The aldehydes and ketones (also known as carbonyl compounds) react with the DNPH to form their respective phenylhydrazone derivatives. For analysis, a portion of the acetonitrile solution is injected into a liquid chromatograph equipped with an ultraviolet detector. External standards of the aldehydes and ketone DNPH derivative are used to quantify the results. Detection limits for this procedure are on the order of 0.01 ppm aldehyde or ketone in exhaust.



Aldehyde and SO<sub>2</sub> Sampling System



Aldehyde Analytical System (HPLC)



SO<sub>2</sub> Analytical Instrumentation (IC)



Particulate Filter Balance

FIGURE 6. SEVERAL VIEWS OF GROUP II AND III SAMPLING AND ANALYSIS SYSTEMS

TABLE 7. SAMPLING AND ANALYSIS METHODOLOGY  
FOR UNREGULATED EMISSIONS

Compound	Sampling	Method of Analysis
Aldehydes and Ketones	Impinger	Dinitrophenylhydrazone derivative. Liquid chromatograph with ultraviolet detector (LC-UV).
Sulfur Dioxide	Impinger	Ion chromatograph
Particulates	47-mm filter	Weighed using microbalance

## 2. Sulfur Dioxide

The concentration of sulfur dioxide in exhaust is determined as sulfate using an ion chromatograph. Sulfur dioxide is collected and converted to sulfate by bubbling dilute exhaust through two glass impingers containing 3-percent hydrogen peroxide absorbing solution. The samples are analyzed on the ion chromatograph and compared to standards of known sulfate concentrations. The detection limit for this procedure is on the order of 0.05 ppm sulfur dioxide in exhaust.

## 3. Particulate

The "particulate" is collected on 47-mm Pallflex filters. The amount of "particulate" collected is determined by weighing the filter on a microbalance before and after sampling. The detection limit for this procedure is on the order of 50  $\mu$ g particulate per cubic meter of exhaust for a 10 minute sampling period.

## B. Accuracy of the Analytical Procedures

A difficult, but very important, endeavor was the determination of procedural accuracy for each analytical method. The primary difficulty involved those procedures in which the exhaust compounds are trapped or absorbed, an extraction or subsequent reaction is performed, and then a portion of the

extraction is analyzed. The decision was reached to initially define the accuracy in terms of a "minimum detection value" (MDV). The MDV, as used in this report, is defined as the value above which it can be said that the compound has been detected in the exhaust (i.e., at a measured value equal to the MDV, the accuracy is equal to plus or minus the MDV). While the determination of accuracy over the entire range of each procedure was beyond the scope of this project, the nominal accuracy for each of the procedures has been estimated to be on the order of  $\pm 10\%$  ( $\pm 25$  for aldehydes other than formaldehyde) at the levels observed in this program.

For compounds collected by bag samples, the MDV can be determined from the instrument detection limits only, and is independent of the sampling rate and duration. However, for compounds which are concentrated in impingers or traps, the MDV is dependent on the instrument detection limit, chemical workup, sampling rate, and sampling duration. The MDVs listed in Table 8 were derived using the listed sampling rate and a 10-minute sampling period.

**TABLE 8. UNREGULATED EMISSION PROCEDURAL SAMPLE RATES AND ACCURACY**

	Sample Flow, <u>ℓ/min</u>	Procedural Minimum Detection Values		MDV for 10 min SS Test, <u>mg/hour</u>
		<u>ppm</u>	<u>μg/m<sup>3</sup></u>	
<u>Aldehydes and Ketones</u>	4			
Formaldehyde		0.01	15	2
Acetaldehyde		0.01	20	2
Acrolein		0.01	25	3
Propionaldehyde		0.01	25	3
Acetone		0.01	25	3
Crotonaldehyde		0.01	30	3
Isobutyraldehyde		0.01	30	3
Methylethylketone		0.01	30	3
Benzaldehyde		0.01	45	5
Hexanaldehyde		0.01	40	5
<u>Sulfur Dioxide</u>	4	0.05	135	15
<u>Particulate</u>	14	----	50	5

#### IV. RESULTS

This section presents the results of emission tests conducted on the three engines evaluated in this study for the Group I (CO, CO<sub>2</sub>, NO<sub>x</sub>, HC, and smoke), Group II (particulate and sulfur dioxide), and Group III (aldehydes and ketones) emissions.

##### A. Group I Emissions

Thirteen-mode emission tests were used as the primary basis of comparison for the Group I emissions, i.e., CO, CO<sub>2</sub>, NO<sub>x</sub>, HC, and smoke opacity. Results of 13-mode emission tests conducted on the three engines are presented in Tables 9 through 11. Computer printouts of the 13-mode gaseous emission tests are included in Appendix Tables A-1 through A-4. Two 13-mode emission tests were run on the Isuzu C-240 (Tables A-1 and A-2) and the results have been averaged for these two tests in Appendix Tables A-5 (g/hp-hr), A-6 (g/hr), and A-7 (ppm or percent). With the exception of a reversal in trend for the CO emissions at 100 percent load, all three engines produced decreasing brake specific emission rates with increasing engine load.

For comparison purposes, the 13-mode gaseous emissions in g/hp-hr have been summarized in Table 12 along with the MIL-T-52932C gaseous emission specifications. Carbon monoxide and oxides of nitrogen emissions were well within the MIL-T-52932C specifications for all three engines. Hydrocarbon emissions for the Teledyne TMD-20 were within specifications; however, the hydrocarbon emissions for the Isuzu C-240 and Peugeot XD3P were equivalent to the MIL-T-52932C (when rounded to tenth of a gram per hp-hr) specification. The Peugeot XD3P gave the lowest CO and NO<sub>x</sub> emissions of the three engines, while the Teledyne TMD-20 gave the lowest HC and BSFC for the three engines.

Table 13 compares the smoke opacity results for the three engines with the MIL-T-52932C specifications. All three engines were within the smoke opacity specification at all specified modes. The highest smoke opacity was observed at 100-percent engine power at both peak torque and rated speeds for all three engines.

TABLE 9. GASEOUS AND SMOKE EMISSIONS (GROUP I) FROM ISUZU C-240 DIESEL ENGINE<sup>a</sup>

Mode	Test Condition		Fuel Consump., lb/hr	Smoke Opacity	Emission Rate, g/hr			Emission Rate, g/hp-hr			Exhaust Concentration		
	Speed	Load, %			HC	CO	NO <sub>x</sub>	HC	CO	NO <sub>x</sub>	HC, ppmC	CO, ppm	NO <sub>x</sub> , ppm
1	Idle	--	1.0	0.8	1	8	9	--	--	--	45	206	123
2	Peak Torque	2	3.5	0.9	11	46	24	10.85	46.15	23.54	163	350	102
3	Peak Torque	25	6.1	1.0	29	35	48	3.07	3.77	5.14	413	259	200
4	Peak Torque	50	8.9	2.0	11	23	67	0.55	1.22	3.61	153	178	298
5	Peak Torque	75	12.7	2.6	7	22	70	0.26	0.80	2.48	105	177	318
6	Peak Torque	100	19.2	15.5	4	314	53	0.11	8.24	1.40	60	2528	250
7	Idle	--	1.3	2.0	2	11	12	--	--	--	73	206	128
8	Rated	100	21.7	7.5	1	149	75	0.03	3.36	1.69	13	1028	310
9	Rated	75	14.2	2.0	6	34	107	0.19	1.07	3.37	73	225	425
10	Rated	50	10.4	2.1	14	30	85	0.68	1.41	4.04	175	192	315
11	Rated	25	7.1	2.1	6	36	60	0.58	3.30	5.58	80	235	220
12	Rated	2	4.7	2.0	10	50	31	16.33	83.82	51.36	123	319	108
13	Rated	--	1.3	2.1	3	16	12	--	--	--	120	294	118

<sup>a</sup>Average of two 13-mode testsComposite 13-Mode Summary  
BSHC = 0.506 gram/bhp-hr  
BSCO = 3.769 gram/bhp-hr  
BSNO<sub>x</sub> = 3.167 gram/bhp-hr  
BSFC = 0.544 lb/bhp-hr

TABLE 10. GASEOUS AND SMOKE EMISSIONS (GROUP I) FROM TELEDYNE TMD-20 DIESEL ENGINE

Mode	Test Condition Speed	Load, %	Fuel Consump., lb/hr	Smoke Opacity	Emission Rate, g/hr			Emission Rate, g/bhp-hr			Exhaust Concentration			CO <sub>2</sub> , %
					HC	CO	NO <sub>x</sub>	HC	CO	NO <sub>x</sub>	HC, ppmC	CO, ppm	NO, ppm	
1	Idle	--	1.0	1.9	4	13	3	--	--	--	170	255	40	1.78
2	Peak Torque	2	2.9	0.7	7	39	23	8.72	45.39	27.43	90	235	95	1.59
3	Peak Torque	25	4.9	0.8	4	16	36	0.44	1.86	4.25	68	149	225	4.21
4	Peak Torque	50	7.2	1.7	3	13	56	0.19	0.79	3.38	55	120	335	6.05
5	Peak Torque	75	10.2	2.2	3	12	73	0.14	0.47	2.93	62	111	450	8.90
6	Peak Torque	100	14.8	7.0	2	74	60	0.06	2.24	1.81	38	748	380	13.69
7	Idle	--	1.2	1.7	4	17	4	--	--	--	145	284	42	1.78
8	Rated	100	17.1	11.5	1	220	67	0.03	6.07	1.85	18	1943	370	13.69
9	Rated	75	12.0	2.0	2	15	79	0.06	0.56	2.89	25	130	430	9.32
10	Rated	50	8.9	1.7	2	14	62	0.10	0.78	3.39	30	120	340	6.81
11	Rated	25	6.0	1.7	5	25	39	0.53	2.82	4.33	75	206	210	4.48
12	Rated	2	3.7	1.7	26	48	17	25.55	47.94	17.23	405	385	93	2.64
13	Rated	--	1.3	1.9	6	20	4	--	--	--	168	304	40	1.73

Composite 13-Mode Summary  
 BSHC = 0.380 gram/bhp-hr  
 BSCO = 2.948 gram/bhp-hr  
 BSNO<sub>x</sub> = 2.966 gram/bhp-hr  
 BSFC = 0.494 lb/bhp-hr

TABLE 11. GASEOUS AND SMOKE EMISSIONS (GROUP 1) FROM PEUGEOT XD3P DIESEL ENGINE

Mode	Test Condition		Fuel Consump., lb/hr	Smoke Opacity	Emission Rate, g/hr			Emission Rate, g/hp-hr			Exhaust Concentration		
	Speed	Load, %			HC	CO	NO <sub>x</sub>	HC	CO	NO <sub>x</sub>	HC, ppmC	CO, ppm	NO <sub>x</sub> , ppm
1	Idle	--	0.9	0.5	4	20	5	--	--	--	197	437	65
2	Peak Torque	2	4.4	1.7	26	83	13	30.95	98.23	15.46	305	490	45
3	Peak Torque	25	6.4	1.5	12	33	27	1.18	3.14	2.63	165	225	110
4	Peak Torque	50	9.4	1.5	10	20	44	0.49	0.98	2.16	132	139	180
5	Peak Torque	75	13.5	1.7	11	18	58	0.34	0.59	1.87	140	130	245
6	Peak Torque	100	19.0	6.3	8	49	55	0.19	1.17	1.32	105	355	240
7	Idle	--	1.1	0.7	6	20	7	--	--	--	205	375	75
8	Rated	100	21.4	5.5	2	87	54	0.05	1.93	1.21	27	577	215
9	Rated	75	14.8	1.2	5	21	57	0.14	0.62	1.67	57	139	220
10	Rated	50	10.3	1.1	5	24	42	0.24	1.06	1.88	67	158	165
11	Rated	25	6.9	1.4	6	32	26	0.50	2.81	2.32	72	206	100
12	Rated	2	4.5	1.5	18	71	12	17.44	68.36	11.79	215	427	43
13	Idle	--	1.3	1.1	5	23	7	--	--	--	145	355	60

Composite 13-Mode Summary

BSHC = 0.527 gram/bhp-hr

BSCO = 2.240 gram/bhp-hr

BSNO<sub>x</sub> = 1.856 gram/bhp-hr

BSFC = 0.503 lb/bhp-hr

TABLE 12. SUMMARY OF COMPOSITE 13-MODE EMISSION RESULTS

Engine Description	13-Mode Emission Results, g/hp-hr			
	HC	CO	NO <sub>x</sub>	BSFC <sup>a</sup>
Isuzu C-240	0.506	3.769	3.167	0.544
Teledyne TMD-20	0.380	2.948	2.966	0.494
Peugeot XD3P	0.527	2.240	1.856	0.503
MIL-T-52932C Specification	0.5	5.0	6.0	NAB <sup>b</sup>

<sup>a</sup>BSFC expressed in lb fuel/hr

<sup>b</sup>NA - denotes not applicable

TABLE 13. COMPARISON OF ISUZU C-240, TELEDYNE TMD-20, AND PEUGEOT XD3P SMOKE OPACITIES WITH THE MIL-T-52932C FUEL

Mode	Engine Power, %	Engine Speed	Smoke Opacity			
			MIL-T-52932C Specifications	Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
1	--	Idle	5.0	0.8	1.9	0.5
2	2	Peak Torque	5.0	0.9	0.7	1.7
3	25	Peak Torque	5.0	1.0	0.8	1.5
4	50	Peak Torque	5.0	2.0	1.7	1.5
5	75	Peak Torque	NR	2.6	2.2	1.7
6	100	Peak Torque	NR	15.5	7.0	6.3
7	--	Idle	5.0	2.0	1.7	0.7
8	100	Rated	NR	7.5	11.5	5.5
9	75	Rated	NR	2.0	2.0	1.2
10	50	Rated	5.0	2.1	1.7	1.1
11	25	Rated	5.0	2.1	1.7	1.4
12	2	Rated	5.0	2.0	1.7	1.5
13	--	Idle	5.0	2.1	1.9	1.1

NR - denotes not regulated

## B. Group II Emissions

Specific analyses included in the Group II analyses were particulate and sulfur dioxide. The emissions were measured at six engine speed and load conditions (idle, peak torque speed/2-percent load, peak torque speed/25-percent load, rated speed/2-percent load, rated speed/50-percent load, and rated speed/100-percent load). Particulate emissions are presented in Table 14 as g/hr, g/hp-hr, and mg/m<sup>3</sup>. Sulfur dioxide emissions are presented in Table 15 as g/hr, g/hp-hr, and ppm. Due to procedural sampling difficulties, it was necessary to calculate the sulfur dioxide emission rates from the engine fuel flow rates and from the sulfur content in the test fuel for the Isuzu C-240 and Teledyne TMD-20 engines. For the Isuzu engine, two of the test points gave measured sulfur dioxide emission rates within 6 percent of the calculated emission rates, however for continuity, only the calculated values are presented in Table 15. These procedural sampling difficulties were solved after the Isuzu C-240 and Teledyne TMD-20 engines had been tested and removed from the test stand. The Peugeot engine, which was tested after the difficulties were solved, gave similar measured and calculated values. The particulate and sulfur dioxide emissions data were compared for the three engines in the study as well as with data reported in an earlier study, "Clean Burning Diesel Engines - Phase II"(2), for two Deutz and two Perkins forklift engines also operating on the EPA DF-2 certification fuel. The results of these comparisons are presented below:

- At idle conditions, the Isuzu C-240 gave lower particulate emissions (g/hr) than either the Teledyne or Peugeot engines. The particulate rate was also lower than the particulate rates for the four engines tested in the previous study.(2)
- The Peugeot XD3P gave higher particulate rates than the Isuzu or the Teledyne engines at the 2-percent load condition for both rated and peak torque speeds.
- At 100-percent load/rated speed, both the Isuzu C-240 and Teledyne TMD-20 gave particulate rates (g/hp and g/hp-hr) higher than those observed for the Peugeot engine and the four engines previously tested.(2)

TABLE 14. SUMMARY OF PARTICULATE EMISSIONS FROM ISUZU C-240,  
TELEDYNE TMD-20, AND PEUGEOT XD3P DIESEL ENGINES

Engine Speed	Load, %	Particulate Emission Rate, g/hr		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	0.29	3.83	3.15
Peak Torque	2	4.84	5.10	11.86
Peak Torque	25	7.69	4.57	9.95
Rated	2	10.34	12.05	37.89
Rated	50	10.01	4.12	9.89
Rated	100	53.1	66.6	23.85

Engine Speed	Load, %	Particulate Emission Rate, g/hp-hr		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	NA	NA	NA
Peak Torque	2	7.96	7.90	18.6
Peak Torque	25	0.81	0.51	0.95
Rated	2	11.49	15.1	29.2
Rated	50	0.48	0.23	0.44
Rated	100	1.22	1.86	0.51

Engine Speed	Load, %	Particulate Concentration, mg/m <sup>3</sup>		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	6	66	61
Peak Torque	2	39	53	90
Peak Torque	25	63	47	75
Rated	2	73	114	264
Rated	50	69	38	68
Rated	100	352	626	165

TABLE 15. SUMMARY OF SULFUR DIOXIDE EMISSIONS FROM ISUZU C-240,  
TELEDYNE TMD-20, AND PEUGEOT XD3P DIESEL ENGINES

Engine Speed	Load, %	Sulfur Dioxide Emission Rate, g/hr		
		Isuzu C-240*	Teledyne TMD-20*	Peugeot XD3P
Idle	--	2.62	3.62	2.51
Peak Torque	2	10.69	8.76	9.44
Peak Torque	25	17.74	15.24	16.76
Rated	2	14.27	10.86	12.99
Rated	50	32.01	26.29	35.81
Rated	100	70.67	53.05	68.75

Engine Speed	Load, %	Sulfur Dioxide Emission Rate, g/hp-hr		
		Isuzu C-240*	Teledyne TMD-20*	Peugeot XD3P
Idle	--	NA	NA	NA
Peak Torque	2	17.29	13.53	10.49
Peak Torque	25	1.87	1.69	1.60
Rated	2	15.86	13.58	9.99
Rated	50	1.52	1.43	1.60
Rated	100	1.62	1.48	1.46

Engine Speed	Load, %	Sulfur Dioxide Concentration, ppm		
		Isuzu C-240*	Teledyne TMD-20*	Peugeot XD3P
Idle	--	21	25	18
Peak Torque	2	33	34	27
Peak Torque	25	54	59	48
Rated	2	38	39	35
Rated	50	83	93	94
Rated	100	176	187	180

\*Calculated from the fuel consumption rate and the percentage of sulfur  
in the fuel

- Sulfur dioxide emissions (g/hr and g/hp-hr) were similar for the three engines.
- On a g/hp-hr basis, the three engines in this study gave sulfur dioxide emission rates similar to those recorded in earlier work.<sup>(2)</sup>

The particulate emission rates have also been compared to the MIL-T-52932C particulate specification in Table 16. All three engines gave particulate emission rates within the MIL-T-52932C specifications for the 25-percent load/peak torque speed and 50-percent load/rated speed modes. Comparable data are not available for the remaining modes.

**TABLE 16. COMPARISON OF ISUZU C-240, TELEDYNE TMD-20, AND PEUGEOT XD3P PARTICULATE EMISSION RATES WITH THE MIL-T-52932C SPECIFICATION**

Mode	Engine Power, %	Engine Speed	Particulate Emissions Rate, g/hr			
			MIL-T-52932C Specifications	Isuzu <sup>a</sup> C-240	Teledyne <sup>a</sup> TMD-20	Peugeot <sup>a</sup> XD3P
1	--	Idle	NR	0.29	3.83	3.15
2	2	Peak Torque	NR	4.84	5.10	11.86
3	25	Peak Torque	15.0	7.69	4.57	9.95
4	50	Peak Torque	15.0	ND	ND	ND
5	75	Peak Torque	NR	ND	ND	ND
6	100	Peak Torque	NR	ND	ND	ND
7	--	Idle	NR	ND	ND	ND
8	100	Rated	NR	53.1	66.6	23.85
9	75	Rated	NR	ND	ND	ND
10	50	Rated	15.0	10.01	4.12	9.89
11	25	Rated	15.0	ND	ND	ND
12	2	Rated	NR	10.34	12.05	37.89
13	--	Idle	NR	ND	ND	ND

<sup>a</sup>Average of two tests (Modes 1, 2, 8)

NR - denotes not regulated

ND - denotes no data (not in test plan)

### C. Group III Emissions

Aldehyde and ketone emissions were evaluated in the Group III analyses. This section presents the results of these analyses for the three test engines. The Group III analyses were performed at idle, peak torque speed/2-percent load, and rated speed/100-percent load. Formaldehyde (the predominate aldehyde detected) and total aldehydes (summation of the 10 aldehydes and ketones evaluated in this study) are presented in Tables 17 and 18, respectively. Emission rates for each of the nine aldehydes and ketones (isobutyraldehyde and methylethylketone are not separated in the analysis and are reported as one compound) are reported individually in Appendix Table B-1. In general, these results are summarized as follows:

- Formaldehyde was the predominate aldehyde detected, generally accounting for 33 to 47 percent of the total aldehydes and ketones detected.
- For all three engines, the formaldehyde as well as the total aldehyde and ketone emissions were ordered as follows: Idle peak torque speed/2-percent load > rated speed/100-percent load.
- Idle and peak torque speed/2-percent load formaldehyde emissions were generally equivalent or higher in this study than in the earlier study<sup>(2)</sup> and inversely the rated speed/100-percent load emissions were equivalent or lower than emissions recorded in the earlier study.<sup>(2)</sup>

### D. Trend Validation

Validation of Group I emissions was accomplished for six modes of the EPA 13-mode cycle. These modes included 2-, 50-, and 100-percent load at rated speed, 2- and 25-percent load at peak torque speed, and idle. The modes include the worst case conditions, i.e., 2-percent load at both speeds. In general, as load is applied, emission rates (g/hp-hr) decrease quite rapidly. During the validation of emission trends, triplicate tests were conducted at 2 percent load at peak torque, 100 percent load at rated speed, and idle, while only duplicate tests

**TABLE 17. SUMMARY OF FORMALDEHYDE EMISSIONS FROM ISUZU C-240, TELEDYNE TMD-20, AND PEUGEOT XD3P DIESEL ENGINES**

Engine Speed	Load, %	Formaldehyde Emission Rate, mg/hr		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	168	506	626
Peak Torque	2	377	945	2400
Rated	100	158	72	199

Engine Speed	Load, %	Formaldehyde Emission Rate, mg/hp-hr		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	--	--	--
Peak Torque	2	753	1350	2667
Rated	100	3.61	1.99	4.18

Engine Speed	Load, %	Formaldehyde Concentration, mg/m <sup>3</sup>		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	3.31	9.25	12.2
Peak Torque	2	3.00	9.64	18.2
Rated	100	1.02	0.68	1.38

**TABLE 18. SUMMARY OF TOTAL ALDEHYDE<sup>a</sup> EMISSIONS FROM ISUZU C-240, TELEDYNE TMD-20, AND PEUGEOT XD3P DIESEL ENGINES**

Engine Speed	Load, %	Total Aldehyde Emission Rate, mg/hr		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	441	1098	1432
Peak Torque	2	1144	2090	5533
Rated	100	336	184	427

Engine Speed	Load, %	Total Aldehyde Emission Rate, mg/hp-hr		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	--	--	--
Peak Torque	2	2288	2986	6148
Rated	100	7.68	5.08	8.94

Engine Speed	Load, %	Total Aldehyde Concentration, mg/m <sup>3</sup>		
		Isuzu C-240	Teledyne TMD-20	Peugeot XD3P
Idle	--	8.72	20.1	27.9
Peak Torque	2	9.15	21.5	42.1
Rated	100	2.18	1.73	2.95

<sup>a</sup>Includes formaldehyde, acetaldehyde, acrolein, propionaldehyde, crotonaldehyde, isobutyraldehyde + methylethylketone, benzaldehyde, and hexanaldehyde

were run on the remaining three modes. Results of the trend validation tests are summarized in Tables 19, 20, and 21. The trends of high brake specific emissions at low load (i.e., 2 percent) and drastically reduced emissions once load is applied are confirmed in the tables. The reversal in the trend of decreasing BSCO with increasing load at the 100 percent load point was also confirmed.

TABLE 19. TREND VALIDATION OF EMISSIONS FROM ISUZU C-240 DIESEL ENGINE

Engine Condition		Run <sup>a</sup>	Measured Exhaust Concentrations				Mass Emissions Rate, g/hr			Brake Specific Emission Rate g/hp-hr		
Speed, rpm	Load, %		HC, ppmC	CO, ppm	CO <sub>2</sub> , %	NO <sub>x</sub> , ppm	HC	CO	NO <sub>x</sub>	HC	CO	NO <sub>x</sub>
2000	2	1	163	350	2.35	102	11	46	24	10.85	46.15	23.54
		2	100	304	2.32	90	7	40	22	8.94	53.67	28.89
		3	130	304	2.27	70	9	40	16	17.24	79.7	31.09
		Avg	131	319	2.31	87	9	42	21	12.34	59.85	27.84
2000	25	1	413	259	4.11	200	29	35	48	3.07	3.77	5.14
		2	265	274	3.95	160	17	35	36	1.84	3.71	3.82
		3	NR <sup>c</sup>	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	339	267	2.69	180	23	35	42	2.46	3.75	4.48
2400	2	1	123	319	2.67	108	10	50	31	16.33	83.82	51.36
		2	140	324	2.54	75	11	52	21	12.61	57.57	23.28
		3	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	132	322	2.61	92	11	51	26	14.47	70.70	37.32
2400	50	1	175	192	6.10	315	14	30	85	0.68	1.41	4.04
		2	290	314	6.13	225	23	47	59	1.08	2.24	2.81
		3	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	233	253	6.12	270	19	39	72	0.88	1.83	3.43
2400	100	1	13	1028	13.69	310	1	149	75	0.03	3.36	1.69
		2	65	956	13.40	240	6	149	64	0.13	3.45	1.48
		3	30	956	13.55	170	2	139	42	0.06	3.18	0.95
		Avg	36	980	13.55	240	3	146	60	0.07	3.33	1.37
725 <sup>b</sup>	--	1	73	206	2.22	128	2	11	12	--	--	--
		2	75	245	2.12	110	1	9	7	--	--	--
		3	130	294	2.17	100	2	10	6	--	--	--
		Avg	93	248	2.17	113	2	10	8	--	--	--

<sup>a</sup>Run 1 - Group I only; Run 2 - Group I, II; Run 3 - Group I, II, III

<sup>b</sup>Mode 7 of 13-mode emissions test

<sup>c</sup>NR - denotes not required in test plan

TABLE 20. TREND VALIDATION OF EMISSIONS FROM TELEDYNE TMD-20 DIESEL ENGINE

Engine Condition Speed, rpm	Load, %	Run <sup>a</sup>	Measured Exhaust Concentrations			Mass Emissions			Brake Specific Emission Rate, g/hp-hr		
			HC, ppmC	CO, ppm	CO <sub>2</sub> , %	HC, g/hr	CO, g/hr	NO <sub>x</sub> , g/hr	HC	CO	NO <sub>x</sub>
2000	2	1	90	235	1.59	95	7	39	23	8.72	45.39
		2	177	406	2.27	63	10	43	13	15.92	72.07
		3	140	406	2.22	60	8	46	12	12.32	70.62
		Avg	136	349	2.03	73	8	43	16	12.32	62.69
2000	25	1	68	149	4.21	225	4	16	36	0.44	1.86
		2	77	177	4.15	185	4	19	36	0.47	2.08
		3	NR <sup>c</sup>	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	73	163	4.18	205	4	18	36	0.46	1.97
2230	2	1	405	385	2.64	93	26	48	17	25.55	47.94
		2	445	544	2.48	60	27	66	13	32.68	78.75
		3	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	425	465	2.56	77	27	57	15	29.12	63.35
2230	50	1	30	120	6.81	340	2	14	62	0.10	0.78
		2	82	158	6.72	265	5	18	52	0.27	0.97
		3	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	56	139	6.77	303	4	16	57	0.19	0.88
2230	100	1	18	1943	13.69	370	1	220	67	0.03	6.07
		2	55	2613	13.69	340	3	284	63	0.09	7.95
		3	45	2387	12.98	290	3	280	57	0.08	7.73
		Avg	39	2314	13.45	339	2	261	62	0.07	7.25
1040 <sup>b</sup>	--	1	168	304	1.73	40	6	20	4	--	--
		2	280	385	1.73	30	9	24	3	--	--
		3	200	355	1.59	30	6	22	3	--	--
		Avg	216	348	1.68	33	7	22	3	--	--

<sup>a</sup>Run 1 - Group I only; Run 2 - Group I, II; Run 3 - Group I, II, III

<sup>b</sup>Mode 7 of 13-mode emissions test

CNR - denotes not required in test plan

TABLE 21. TREND VALIDATION OF EMISSIONS FROM PEUGEOT XD3P DIESEL ENGINE

Engine Condition Speed, rpm	Load, %	Run <sup>a</sup>	Measured Exhaust Concentrations				Mass Emissions Rate, g/hr			Brake Specific Emission Rate, g/hp-hr		
			HC, ppmC	CO, ppm	CO <sub>2</sub> , %	NO <sub>x</sub> , ppm	HC	CO	NO <sub>x</sub>	HC	CO	NO <sub>x</sub>
2100	2	1	305	409	2.32	45	26	83	13	30.95	98.23	15.46
		2	210	406	2.17	40	13	50	7	16.62	63.65	9.50
		3	260	511	2.02	35	20	78	8	22.50	87.76	9.20
		Avg	258	469	2.17	40	20	70	9	23.36	83.21	11.39
2100	25	1	165	225	4.01	110	12	33	27	1.18	3.14	2.63
		2	82	206	3.89	110	7	33	26	0.64	3.13	2.47
		3	NR <sup>c</sup>	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	124	216	3.95	110	10	33	27	0.91	3.14	2.55
2300	2	1	215	427	2.43	43	18	71	12	17.44	68.36	11.79
		2	280	511	2.32	40	22	78	9	16.39	59.16	7.00
		3	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	248	469	2.38	42	20	75	11	16.92	63.76	9.40
2300	50	1	67	158	6.22	165	5	24	42	0.24	1.06	1.88
		2	78	206	6.13	190	6	30	43	0.27	1.36	1.92
		3	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
		Avg	73	182	6.18	178	6	27	43	0.26	1.21	1.90
2300	100	1	27	577	12.94	215	2	87	54	0.05	1.93	1.21
		2	45	375	12.43	255	4	55	59	0.08	1.36	1.92
		3	65	304	12.57	255	6	49	63	0.12	1.02	1.32
		Avg	46	419	12.65	242	4	64	59	0.08	1.44	1.48
800 <sup>b</sup>	--	1	205	375	1.83	75	6	20	7	--	--	--
		2	85	294	1.59	55	4	25	7	--	--	--
		3	130	345	1.64	50	6	30	7	--	--	--
		Avg	140	338	1.69	60	5	25	7	--	--	--

<sup>a</sup>Run 1 - Group I only; Run 2 - Group I, II; Run 3 - Group I, II, III<sup>b</sup>Mode 7 of 13-mode emissions test

CNR - denotes not required in test plan

## V. SUMMARY

This section summarizes emission results from the Isuzu C-240, the Teledyne TMD-20, and the Peugeot XD3P engines for Groups I, II, and III emissions. Data for the Group I emissions provided the following observations:

- Carbon monoxide and oxides of nitrogen emissions were well within the MIL-T-52932C specifications for all three engines. Hydrocarbon emissions for the Teledyne TMD-20 were also within specification; however, the hydrocarbon emissions for the Isuzu C-240 and the Peugeot XD3P were equivalent to the MIL-T-52932C specification.
- With the exception of a reversal in trend for the CO emissions at 100-percent load, all three engines produced decreasing brake specific emission rates with increasing engine load.
- All three engines were within the MIL-T-52932C smoke specifications at all specified modes.

Observations for results of Group II emissions for particulate and sulfur dioxide are summarized below:

- Sulfur dioxide emissions (g/hr, and g/hp-hr) were similar for the three test engines in this study, and on a g/hp-hr basis, were similar to emissions recorded in previous forklift engine emission characterization studies.
- Brake specific particulate and sulfur dioxide emission rates are highest under low load conditions.
- Sulfur dioxide emissions (g/hr) are related to fuel consumption rates and increase with increasing engine fuel consumption.

Observations for the Group III aldehydes and ketones includes:

- Formaldehyde was the predominate aldehyde detected and accounted for

- 33 to 47 percent of the total aldehydes and ketones detected.
- For all three engines, the formaldehyde as well as the total aldehyde and ketone emissions were ordered as follows: idle peak torque/2-percent load > rated speed/100-percent load.

Results of this study have increased the data base of emissions data to allow assessment of the potential problems when operating diesel engines in areas with limited ventilation.

## VI. REFERENCES

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2. Dietzmann, Harry E., "Clean-Burning Diesel Engines - Phase II." Interim Report AFLRL No. 178, AD A152606, U.S. Army Belvoir R&D Center, Contract No. DAAK70-85-C-0007, December 1984.
3. Code of Federal Regulations, Title 40, Part 86, Subpart D, "Emission Regulations for New Gasoline-Fueled and Diesel Heavy-Duty Engines; Gaseous Exhaust Test Procedures," pp 428-460, 1 July 1982.
4. Smith, L.R., Parness, M.A., Fanick, E.R., Dietzmann, H.E., "Analytical Procedures for Characterizing Unregulated Emissions From Vehicles Using Middle-Distillate Fuels," EPA 600/2-80-068, April 1980.
5. Code of Federal Regulations, Title 40, Part 86, Subpart B, "Emission Regulations for 1977 and Later Model Year New Light-Duty Vehicles and New Light-Duty Trucks; Test Procedures," (particulate tunnel and sampling system) pp 402-465, 1 July 1983.

## APPENDIX A

### 13-MODE GASEOUS EMISSIONS RESULTS

- TABLE A-1. 13-MODE GASEOUS EMISSION RESULTS FROM ISUZU C-240  
(8-19-85)
- TABLE A-2. 13-MODE GASEOUS EMISSION RESULTS FROM ISUZU C-240  
(8-22-85)
- TABLE A-3. 13-MODE GASEOUS EMISSION RESULTS FROM TELEDYNE  
TMD 20
- TABLE A-4. 13-MODE GASEOUS EMISSION RESULTS FROM PEUGEOT XD3P
- TABLE A-5. AVERAGE OF TWO 13-MODE EMISSION RESULTS ON ISUZU  
C-240 (g/hp-hr)
- TABLE A-6. AVERAGE OF TWO 13-MODE EMISSION RESULTS ON ISUZU  
C-240 (g/hr)
- TABLE A-7. AVERAGE OF TWO 13-MODE EMISSION RESULTS ON ISUZU  
C-240 (ppm or percent)

TABLE A-1. 13-MODE GASEOUS EMISSIONS RESULTS FROM ISUZU C-240 (8-19-85)

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979												
ENGINE: ISUZU C-240 636922				PROJECT: 02-8341-175				DATE: 8/19/85				
TEST-4				FUEL: EM-627-F								
MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL LB/MIN	AIR LB/MIN	FLOW GR/LB	INTAKE HUMID GR/LB	NOX CORR FACT	HC PPM	CO PPM	NOX PCT
1	1	IDLE / 725.	0.	0.	0.017	1.92	111.	1.11	1.11	45.	206.	2.22
2	2	INTER / 2000.	3.	1.0	0.058	5.33	111.	1.11	1.11	125.	334.	2.38
3	25	INTER / 2000.	25.	9.5	0.102	5.33	111.	1.11	1.11	365.	204.	4.21
4	50	INTER / 2000.	49.	18.5	0.147	5.27	123.	1.13	1.13	145.	187.	6.38
5	75	INTER / 2000.	74.	28.0	0.213	5.23	128.	1.14	1.14	100.	177.	9.42
6	100	INTER / 2000.	100.	38.0	0.322	5.22	128.	1.07	1.07	60.	2733.	14.13
7	100	IDLE / 725.	0.	0.	0.025	1.86	121.	1.13	1.13	60.	206.	2.22
8	100	RATED / 2400.	96.	43.8	0.362	6.14	84.	1.02	1.02	10.	1034.	13.69
9	75	RATED / 2400.	70.	31.8	0.240	6.12	84.	1.01	1.01	75.	225.	8.69
10	50	RATED / 2400.	46.	21.0	0.175	6.20	100.	1.05	1.05	190.	196.	6.22
11	25	RATED / 2400.	24.	10.8	0.120	6.16	115.	1.08	1.08	80.	235.	4.35
12	2	RATED / 2400.	1.	0.6	0.075	6.18	115.	1.12	1.12	125.	314.	2.70
13	1	IDLE / 725.	0.	0.	0.025	1.89	107.	1.10	1.10	135.	304.	2.22
MODE	HC	CO	NOX	GRAMS/LB-FUEL	HC	CO	NOX	GRAMS/BHP-HR	HC	CO	NOX	MODE
1	.93	8.43	8.17	*****	*****	*****	*****	*****	*****	*****	*****	1
2	2.40	12.66	6.91	8.40	44.29	24.20	*****	*****	*****	*****	*****	2
3	4.05	4.39	7.38	2.60	2.82	4.74	*****	*****	*****	*****	*****	3
4	1.09	2.68	7.43	.52	1.27	3.53	*****	*****	*****	*****	*****	4
5	.52	1.72	5.31	.24	.79	2.43	*****	*****	*****	*****	*****	5
6	.21	17.44	2.46	.11	8.66	1.25	*****	*****	*****	*****	*****	6
7	1.24	8.43	8.37	*****	*****	*****	*****	*****	*****	*****	*****	7
8	.04	6.89	3.46	.02	3.41	1.72	*****	*****	*****	*****	*****	8
9	.42	2.37	7.76	.19	1.07	3.52	*****	*****	*****	*****	*****	9
10	1.46	2.88	8.60	.75	1.44	4.30	*****	*****	*****	*****	*****	10
11	.87	4.93	8.91	.58	3.29	5.94	*****	*****	*****	*****	*****	11
12	2.13	10.52	7.06	15.96	78.89	52.95	*****	*****	*****	*****	*****	12
13	2.77	12.34	8.39	*****	*****	*****	*****	*****	*****	*****	*****	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ----- = .480 GRAM/BHP-HR  
 BSNOX ----- = 3.858 GRAM/BHP-HR  
 BSNOX ----- = 3.208 GRAM/BHP-HR  
 BSHC + BSNOX ----- = 3.687 GRAM/BHP-HR  
 CORR. BSFC ----- = .547 LBS/BHP-HR

TABLE A-2. 13-MODE GASEOUS EMISSIONS RESULTS FROM ISUZU C-240 (8-22-85)

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979												
ENGINE: ISUZU C-240 636922      PROJECT: 02-8341-175      DATE: 8/22/85												
TEST-5      FUEL: EM-627-F												
MODE	POWER PCT	ENGINE COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	HC PPM	CO PPM	NOX PCT	MODE
1	2	3	4	5	6	7	8	9	10	11	12	13
1	100	2000	0.	0.	0.015	1.96	82.	1.028	45.	206.	2.17	135.
2	100	2000	3.	1.0	0.057	5.37	82.	1.035	200.	365.	2.32	103.
3	25	2000	24.	9.0	0.100	5.33	98.	1.076	460.	314.	4.01	210.
4	50	2000	49.	18.5	0.148	5.25	89.	1.028	160.	168.	6.30	315.
5	75	2000	74.	28.0	0.212	5.25	89.	1.026	110.	177.	9.21	335.
6	100	2000	100.	38.0	0.318	5.23	89.	1.025	60.	2322.	13.84	280.
7	100	2000	0.	0.	0.017	1.88	89.	1.027	85.	206.	2.22	145.
8	100	2400	97.	44.4	0.360	6.34	85.	1.012	15.	1021.	13.69	310.
9	75	2400	70.	31.8	0.232	6.20	85.	1.018	70.	225.	8.39	405.
10	50	2400	46.	21.0	0.170	6.30	104.	1.070	160.	187.	5.97	290.
11	25	2400	24.	10.8	0.115	6.26	109.	1.111	80.	235.	4.15	205.
12	2	2400	1.	0.	0.080	6.26	105.	1.115	120.	324.	2.64	100.
13	100	725	0.	0.	0.018	1.96	99.	1.095	105.	284.	2.22	120.

MODE	POWER PCT	ENGINE COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	HC PPM	CO PPM	NOX PCT	MODE
1	2	3	4	5	6	7	8	9	10	11	12	13
1	100	2000	0.	0.	0.015	1.96	82.	1.028	45.	206.	2.17	135.
2	100	2000	3.	1.0	0.057	5.37	82.	1.035	200.	365.	2.32	103.
3	25	2000	24.	9.0	0.100	5.33	98.	1.076	460.	314.	4.01	210.
4	50	2000	49.	18.5	0.148	5.25	89.	1.028	160.	168.	6.30	315.
5	75	2000	74.	28.0	0.212	5.25	89.	1.026	110.	177.	9.21	335.
6	100	2000	100.	38.0	0.318	5.23	89.	1.025	60.	2322.	13.84	280.
7	100	2000	0.	0.	0.017	1.88	89.	1.027	85.	206.	2.22	145.
8	100	2400	97.	44.4	0.360	6.34	85.	1.012	15.	1021.	13.69	310.
9	75	2400	70.	31.8	0.232	6.20	85.	1.018	70.	225.	8.39	405.
10	50	2400	46.	21.0	0.170	6.30	104.	1.070	160.	187.	5.97	290.
11	25	2400	24.	10.8	0.115	6.26	109.	1.111	80.	235.	4.15	205.
12	2	2400	1.	0.	0.080	6.26	105.	1.115	120.	324.	2.64	100.
13	100	725	0.	0.	0.018	1.96	99.	1.095	105.	284.	2.22	120.

MODE	POWER PCT	ENGINE COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	HC PPM	CO PPM	NOX PCT	MODE
1	2	3	4	5	6	7	8	9	10	11	12	13
1	100	2000	0.	0.	0.015	1.96	82.	1.028	45.	206.	2.17	135.
2	100	2000	3.	1.0	0.057	5.37	82.	1.035	200.	365.	2.32	103.
3	25	2000	24.	9.0	0.100	5.33	98.	1.076	460.	314.	4.01	210.
4	50	2000	49.	18.5	0.148	5.25	89.	1.028	160.	168.	6.30	315.
5	75	2000	74.	28.0	0.212	5.25	89.	1.026	110.	177.	9.21	335.
6	100	2000	100.	38.0	0.318	5.23	89.	1.025	60.	2322.	13.84	280.
7	100	2000	0.	0.	0.017	1.88	89.	1.027	85.	206.	2.22	145.
8	100	2400	97.	44.4	0.360	6.34	85.	1.012	15.	1021.	13.69	310.
9	75	2400	70.	31.8	0.232	6.20	85.	1.018	70.	225.	8.39	405.
10	50	2400	46.	21.0	0.170	6.30	104.	1.070	160.	187.	5.97	290.
11	25	2400	24.	10.8	0.115	6.26	109.	1.111	80.	235.	4.15	205.
12	2	2400	1.	0.	0.080	6.26	105.	1.115	120.	324.	2.64	100.
13	100	725	0.	0.	0.018	1.96	99.	1.095	105.	284.	2.22	120.

MODE	POWER PCT	ENGINE COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	HC PPM	CO PPM	NOX PCT	MODE
1	2	3	4	5	6	7	8	9	10	11	12	13
1	100	2000	0.	0.	0.015	1.96	82.	1.028	45.	206.	2.17	135.
2	100	2000	3.	1.0	0.057	5.37	82.	1.035	200.	365.	2.32	103.
3	25	2000	24.	9.0	0.100	5.33	98.	1.076	460.	314.	4.01	210.
4	50	2000	49.	18.5	0.148	5.25	89.	1.028	160.	168.	6.30	315.
5	75	2000	74.	28.0	0.212	5.25	89.	1.026	110.	177.	9.21	335.
6	100	2000	100.	38.0	0.318	5.23	89.	1.025	60.	2322.	13.84	280.
7	100	2000	0.	0.	0.017	1.88	89.	1.027	85.	206.	2.22	145.
8	100	2400	97.	44.4	0.360	6.34	85.	1.012	15.	1021.	13.69	310.
9	75	2400	70.	31.8	0.232	6.20	85.	1.018	70.	225.	8.39	405.
10	50	2400	46.	21.0	0.170	6.30	104.	1.070	160.	187.	5.97	290.
11	25	2400	24.	10.8	0.115	6.26	109.	1.111	80.	235.	4.15	205.
12	2	2400	1.	0.	0.080	6.26	105.	1.115	120.	324.	2.64	100.
13	100	725	0.	0.	0.018	1.96	99.	1.095	105.	284.	2.22	120.

MODE	POWER PCT	ENGINE COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	HC PPM	CO PPM	NOX PCT	MODE
1	2	3	4	5	6	7	8	9	10	11	12	13
1	100	2000	0.	0.	0.015	1.96	82.	1.028	45.	206.	2.17	135.
2	100	2000	3.	1.0	0.057	5.37	82.	1.035	200.	365.	2.32	103.
3	25	2000	24.	9.0	0.100	5.33	98.	1.076	460.	314.	4.01	210.
4	50	2000	49.	18.5	0.148	5.25	89.	1.028	160.	168.	6.30	315.
5	75	2000	74.	28.0	0.212	5.25	89.	1.026	110.	177.	9.21	335.
6	100	2000	100.	38.0	0.318	5.23	89.	1.025	60.	2322.	13.84	280.
7	100	2000	0.	0.	0.017	1.88	89.	1.027	85.	206.	2.22	145.
8	100	2400	97.	44.4	0.360	6.34	85.	1.012	15.	1021.	13.69	310.
9	75	2400	70.	31.8	0.232	6.20	85.	1.018	70.	225.	8.39	405.
10	50	2400	46.	21.0	0.170	6.30	104.	1.070	160.	187.	5.97	290.
11	25	2400	24.	10.8	0.115	6.26	109.	1.111	80.	235.	4.15	205.
12	2	2400	1.	0.	0.080	6.26	105.	1.115	120.	324.	2.64	100.
13	100	725	0.	0.	0.018	1.96	99.	1.095	105.	284.	2.22	120.

MODE	POWER PCT	ENGINE COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	HC PPM	CO PPM	NOX PCT	MODE
1	2	3	4	5	6	7	8	9	10	11	12	13
1	100	2000	0.	0.	0.015	1.96	82.	1.028	45.	206.	2.17	135.
2	100	2000	3.	1.0	0.057	5.37	82.	1.035	200.	365.	2.32	103.
3	25	2000	24.	9.0	0.100	5.33	98.	1.076	460.	314.	4.01	210.
4	50	2000	49.	18.5	0.148	5.25	89.	1.028	160.	168.	6.30	315.
5	75	2000	74.	28.0	0.212	5.25	89.	1.026	110.	177.	9.21	335.
6	100	2000	100.	38.0	0.318	5.23	89.	1.025	60.	2322.	13.84	280.
7	100	2000	0.	0.	0.017	1.88	89.	1.027	85.	206.	2.22	145.
8	100	2400	97.	44.4	0.360	6.34	85.	1.012	15.	1021.	13.69	310.
9	75	2400	70.	31.8	0.232	6.20	85.	1.018	70.	225.	8.39	405.
10	50	2400	46.	21.0	0.170	6.30	104.	1.070	160.	187.	5.97	290.
11	25	2400	24.	10.8	0.115	6.26	109.	1.111	80.	235.	4.15	205.
12	2	2400	1.	0.	0.080	6.26	105.	1.115	120.	324.	2.64	100.
13	100	725	0.	0.	0.018	1.96	99.	1.095	105.	284.	2.22	120.

MODE	POWER PCT	ENGINE COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	HC PPM	CO PPM	NOX PCT	MODE
1	2	3	4	5	6	7	8	9	10	11	12	13
1	100	2000	0.	0.	0.015	1.96	82.	1.028	45.	206.	2.17	135.
2	100	2000	3.	1.0	0.057	5.37	82.	1.035	200.	365.	2.32	103.
3	25	2000	24.	9.0	0.100	5.33	98.	1.076	460.	314.	4.01	210.
4	50	2000	49.	18.5	0.148	5.25	89.	1.028	160.	168.	6.30	315.
5	75	2000	74.	28.0	0.212	5.25	89.	1.026	110.	177.	9.21	335.
6	100	2000	100.	38.0	0.318	5.23	89.	1.025	60.	2322.	13.84	280.
7	100	2000	0.	0.	0.017	1.88	89.	1.027	85.	206.	2.22	145.
8	100	2400	97.	44.4	0.360	6.34	85.	1.012	15.	1021.	13.69	310.
9	75	2400	70.	31.8	0.232	6.20	85.	1.018	70.	225.	8.39	405.
10	50	2400	46.	21.0	0.170	6.30	104.	1.070	160.	187.	5.97	290.
11	25	2400	24.	10.8	0.115	6.26	109.	1.111	80.	235.	4.15	205.
12	2	2400	1.	0.	0.080	6.26	105.					

TABLE A-3. 13-MODE GASEOUS EMISSIONS RESULTS FROM TELEDYNE TMD 20

13-MODE FEDERAL DIESEL EMISSION CYCLE 1978												
ENGINE: TELEDYNE TMD 20-107PT SERIAL NO. 300392												
TEST-1 FUEL: EN-827-F PROJECT: 02-8841-175 DATE: 11/7/85												
MODE	POWER PCT	ENGINE SPEED RPM	TORQUE OBS LB-FT	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX FACT	HC PPM	CO PPM	NOX PCT	NOX PPM	MODE
1	1	IDLE / 1040.	0.	.017	2.31	48.	.901	170.	255.	1.78	40.	1
2	2	INTER / 2000.	2.	.048	4.24	48.	.918	80.	235.	1.59	65.	2
3	25	INTER / 2000.	22.	.082	4.20	48.	.926	88.	149.	4.21	225.	3
4	50	INTER / 2000.	43.	.120	4.18	48.	.935	55.	120.	8.05	335.	4
5	75	INTER / 2000.	68.	.150	4.07	48.	.951	52.	111.	8.80	450.	5
6	100	INTER / 2000.	87.	.170	4.04	47.	.973	38.	748.	13.88	380.	6
7	100	IDLE / 1040.	0.	.020	2.25	47.	.988	145.	284.	1.78	42.	7
8	100	RATED / 2230.	85.	.285	4.43	47.	.980	18.	1943.	13.89	370.	8
9	75	RATED / 2230.	64.	.200	4.51	48.	.953	25.	130.	9.32	430.	9
10	50	RATED / 2230.	43.	.148	4.54	48.	.937	30.	120.	8.81	340.	10
11	25	RATED / 2230.	21.	.100	4.61	48.	.923	75.	208.	4.48	210.	11
12	2	RATED / 2230.	2.	.082	4.61	48.	.912	405.	386.	2.84	83.	12
13	1	IDLE / 1040.	0.	.022	2.29	48.	.907	168.	304.	1.73	40.	13

MODE	HC	CO	NOX	HC	CO	NOX	HC	CO	NOX	HC	CO	NOX	MODE
1	4.31	12.85	2.86	8.72	45.38	27.43	.0073	.0680	.105	.0088	18.7	1.015	1
2	2.56	13.30	8.04	.44	1.86	4.25	.0115	.0680	.168	.0077	-33.0	1.040	2
3	.78	3.23	7.37	.19	.78	3.38	.0196	.0680	.284	.0198	1.2	1.040	3
4	.43	1.82	7.74	.14	.47	2.83	.0281	.0680	.421	.0282	-3.0	1.038	4
5	.34	1.14	7.19	.14	.47	2.83	.0421	.0680	.810	.0409	-2.7	1.037	5
6	.14	4.88	4.03	.08	2.24	1.61	.0614	.0680	.888	.0618	.8	1.038	6
7	3.67	14.31	3.10	.0089	.0680	.128	.0089	.0680	.888	.0088	-3.3	1.015	7
8	.07	12.85	3.82	.03	6.07	1.85	.0648	.0680	.839	.0625	-3.6	1.048	8
9	.13	1.28	6.58	.08	.56	2.88	.0447	.0680	.848	.0428	-4.3	1.050	9
10	.21	1.82	7.00	.10	.78	3.38	.0329	.0680	.478	.0318	-3.8	1.050	10
11	.78	4.20	6.44	.53	2.82	4.33	.0218	.0680	.317	.0211	-3.5	1.052	11
12	8.83	13.00	4.87	25.65	47.94	17.23	.0135	.0680	.195	.0128	-4.8	1.052	12
13	4.38	15.71	3.08	.0085	.0680	.138	.0085	.0680	.882	.0084	-11.5	1.014	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC = .380 GRAM/BHP-HR  
 BSOC = 2.848 GRAM/BHP-HR  
 BSNOX = 2.988 GRAM/BHP-HR  
 BSHC + BSNOX = 3.346 GRAM/BHP-HR  
 CORR. BSFC = .484 LBS/BHP-HR

13-MODE FEDERAL DIESEL EMISSION CYCLE 1978

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

TABLE A-5. AVERAGE OF TWO 13-MODE EMISSION RESULTS (G/HP-HR) ON ISUZU C-240 DIESEL ENGINE

Mode	Engine Condition		Hydrocarbons			Carbon Monoxide			Oxides of Nitrogen		
	Speed, rpm	Load, %	8-19-85	8-22-85	Avg.	8-19-85	8-22-85	Avg.	8-19-85	8-22-85	Avg.
1	725	--	--	--	--	--	--	--	--	--	--
2	2000	2	8.40	13.30	10.85	44.29	48.00	46.15	24.20	22.88	23.54
3	2000	25	2.60	3.54	3.07	2.82	4.71	3.77	4.74	5.53	5.14
4	2000	50	0.52	0.58	0.55	1.27	1.17	1.22	3.53	3.69	3.61
5	2000	75	0.24	0.27	0.26	0.79	0.80	0.80	2.43	2.53	2.48
6	2000	100	0.11	0.11	0.11	8.86	7.62	8.24	1.25	1.54	1.40
7	725	--	--	--	--	--	--	--	--	--	--
8	2400	100	0.02	0.03	0.03	3.41	3.31	3.36	1.72	1.66	1.69
9	2400	75	0.19	0.18	0.19	1.07	1.07	1.07	3.52	3.21	3.37
10	2400	50	0.73	0.62	0.68	1.44	1.39	1.41	4.30	3.77	4.04
11	2400	25	0.58	0.58	0.58	3.29	3.30	3.30	5.94	5.22	5.58
12	2400	2	15.96	16.69	16.33	78.89	88.75	83.82	52.95	49.77	51.36
13	725	--	--	--	--	--	--	--	--	--	--
13-Mode Composite			0.480	0.532	0.506	3.858	3.680	3.769	3.208	3.126	3.167



TABLE A-7. AVERAGE OF TWO 13-MODE EMISSION RESULTS (PPM or PERCENT) ON ISUZU C-240 DIESEL ENGINE

Mode	Engine Condition Speed, rpm      Load, %		Emission Rate, g/hp-hr											
			Hydrocarbons		Carbon Monoxide		Oxides of Nitrogen		Carbon Dioxide, %					
			8-19-85	8-22-85	Avg.	8-19-85	8-22-85	Avg.	8-19-85	8-22-85	Avg.	8-19-85	8-22-85	Avg.
1	725	--	45	45	45	206	206	206	110	135	123	2.22	2.17	2.20
2	2000	2	125	200	163	334	365	350	100	103	102	2.38	2.32	2.35
3	2000	25	365	460	413	204	314	259	190	210	200	4.21	4.01	4.11
4	2000	50	145	160	153	187	168	178	280	315	298	6.38	6.30	6.34
5	2000	75	100	110	105	177	177	177	300	335	318	9.42	9.21	9.32
6	2000	100	60	60	60	2733	2322	2528	220	280	250	14.13	13.84	13.99
7	725	--	60	85	73	206	206	206	110	145	128	2.22	2.22	2.22
8	2400	100	10	15	13	1034	1021	1028	310	310	310	13.69	13.69	13.69
9	2400	75	75	70	73	225	225	225	445	405	425	8.69	8.39	8.54
10	2400	50	190	160	175	196	187	192	340	290	315	6.22	5.97	6.10
11	2400	25	80	80	80	235	235	235	235	205	220	4.35	4.15	4.25
12	2400	2	125	120	123	314	324	319	115	110	108	2.70	2.64	2.67
13	725	--	135	105	120	304	284	294	115	120	118	2.22	2.22	2.22

**APPENDIX B**

**SUMMARY OF ALDEHYDE AND KETONES EMISSION RATES  
FROM ISUZU C-240, TELEDYNE TMD-20, AND  
PEUGEOT XD3P DIESEL ENGINES**

TABLE B-1. SUMMARY OF ALDEHYDE AND KETONES EMISSION RATES FROM  
ISUZU C-240, TELEDYNE TMD-20, AND PEUGEOT XD3P DIESEL ENGINES

Engine Speed	Engine Load,%	Isuzu C-240			Teledyne TMD-20			Peugeot XD3P		
		mg/hr	mg/hp-hr	mg/m <sup>3</sup>	mg/hr	mg/hp-hr	mg/m <sup>3</sup>	mg/hr	mg/hp-hr	mg/m <sup>3</sup>
Formaldehyde										
Idle	--	168	--	3.31	506	--	9.25	626	-	12.2
Peak Torque	2	377	753	3.00	945	1350	9.72	2400	2667	18.2
Rated	100	158	3.61	1.02	72	1.99	0.68	199	4.18	1.38
Acetaldehyde										
Idle	--	91	--	1.80	218	--	3.98	269	--	5.25
Peak Torque	2	219	437	1.75	379	541	3.90	900	1000	6.84
Rated	100	28	0.64	0.18	48	1.32	0.45	18	0.38	0.13
Acrolein										
Idle	--	79	-	1.57	191	--	3.49	233	--	4.55
Peak Torque	2	251	502	2.01	364	520	3.74	839	932	6.38
Rated	100	14	0.32	0.09	18	0.51	0.17	95	1.98	0.65
Acetone										
Idle	--	20	--	0.38	12	--	0.23	65	--	1.27
Peak Torque	2	10	20	0.08	43	61	0.44	29	32	0.22
Rated	100	25	0.57	0.16	42	1.16	0.40	33	0.70	0.23
Propionaldehyde										
Idle	--	28	--	0.54	49	--	0.90	57	--	1.11
Peak Torque	2	64	128	0.51	92	132	0.95	258	287	1.96
Rated	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Crotonaldehyde										
Idle	--	18	--	0.36	37	--	0.68	40	--	0.79
Peak Torque	2	50	99	0.40	89	127	0.91	254	282	1.93
Rated	100	11	0.26	0.07	ND	ND	ND	18	0.38	0.13
Isobutyraldehyde + MEK										
Idle	--	20	--	0.39	45	--	0.83	91	--	1.77
Peak Torque	2	64	127	0.51	62	89	0.64	460	511	3.49
Rated	100	84	1.92	0.54	ND	ND	ND	44	0.91	0.30
Benzaldehyde										
Idle	--	9.5	--	0.19	23	--	0.43	40	--	0.77
Peak Torque	2	69	138	0.55	99	141	1.02	218	242	1.66
Rated	100	16	0.36	0.10	3.8	0.10	0.04	19	0.41	0.13
Hexanaldehyde										
Idle	--	8.9	--	0.18	16	--	0.29	11	--	0.22
Peak Torque	2	42	83	0.33	17	25	0.18	175	195	1.33
Rated	100	ND	ND	ND	ND	ND	ND	ND	ND	ND

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CDR TRADOC COMBINED ARMS TEST ACTIVITY ATTN: ATCT-CA 1 FORT HOOD TX 76544	CDR, US ARMY ARMAMENT MUNITIONS & CHEMICAL COMMAND ARMAMENT RESEARCH & DEVELOPMENT CTR ATTN: AMSMC-LC 1 AMSMC-SC 1 DOVER NJ 07801-5001
CDR US ARMY LEA ATTN: DALO-LEP 1 NEW CUMBERLAND ARMY DEPOT NEW CUMBERLAND PA 17070	CDR, US ARMY TROOP SUPPORT COMMAND ATTN: AMSTR-ME 1 AMSTR-S 1 AMSTR-E 1 AMSTR-WL (MR BRADLEY) 1 4300 GOODFELLOW BLVD ST LOUIS MO 63120-1798
CDR US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY ATTN: STRGP-FW (MR PRICE) 1 BLDG 247, DEFENSE DEPOT TRACY TRACY CA 95376-5051	CDR CONSTRUCTION ENG RSCH LAB ATTN: CERL-EM 1 CERL-ES (MR CASE) 1 CERL-EH 1 P O BOX 4005 CHAMPAIGN IL 61820
PROJ MGR, LIGHT ARMORED VEHICLES ATTN: AMCPM-LA-E 1 WARREN MI 48397	TRADOC LIAISON OFFICE ATTN: ATFE-LO-AV 1 4300 GOODFELLOW BLVD ST LOUIS MO 63120-1798
CDR US ARMY ORDNANCE CENTER & SCHOOL ATTN: ATSL-CD-CS 1 ABERDEEN PROVING GROUND MD 21005	CDR US ARMY QUARTERMASTER SCHOOL ATTN: ATSM-CD 1 ATSM-TD 1 ATSM-PFS (MR ELLIOTT) 1 FORT LEE VA 23801
CDR US ARMY FOREIGN SCIENCE & TECH CENTER ATTN: AMXST-MT-1 1 AMXST-BA 1 FEDERAL BLDG CHARLOTTESVILLE VA 22901	HQ US ARMY TRAINING & DOCTRINE CMD ATTN: ATCD-SL-5 (MAJ JONES) 1 FORT MONROE VA 23651-5000
PROJECT MANAGER, LIGHT COMBAT VEHICLES ATTN: AMCPM-LCV-TC 1 WARREN, MI 48397	

CDR US ARMY NATICK RES & DEV LAB ATTN: STRNA-YE (DR KAPLAN) STRNA-U NATICK MA 01760-5000	1 1	DIR US ARMY MATERIALS TECHNOLOGY LABORATORY ATTN: SLCMT-M SLCMT-EM (DR FOPIANO) WATERTOWN MA 02172-2796	1 1
DIRECTOR US ARMY RSCH & TECH LAB (AVSCOM) PROPULSION LABORATORY ATTN: SAVDL-PL-D (MR ACURIO) 21000 BROOKPARK ROAD CLEVELAND OH 44135-3127	1	PROG MGR, TANK SYSTEMS ATTN: AMCPM-GCM-SM AMCPM-M60 WARREN MI 48397	1 1
CDR US ARMY TRANSPORTATION SCHOOL ATTN: ATSP-CD-MS (MR HARNET) FORT EUSTIS VA 23604-5000	1	CHIEF, U.S. ARMY LOGISTICS ASSISTANCE OFFICE, FORSCOM ATTN: AMXLA-FO (MR PITTMAN) FT MCPHERSON GA 30330	1
PROJ MGR, PATRIOT PROJ OFFICE ATTN: AMCPM-MD-T-C U.S. ARMY MISSILE COMMAND REDSTONE ARSENAL AL 35898	1	<b>DEPARTMENT OF THE NAVY</b>	
HQ, US ARMY ARMOR CENTER AND FORT KNOX ATTN: ATSB-CD FORT KNOX KY 40121	1	CDR NAVAL AIR PROPULSION CENTER ATTN: PE-33 (MR D'ORAZIO) PE-32 (MR MANGIONE) P O BOX 7176 TRENTON NJ 06828	1 1
CDR COMBINED ARMS COMBAT DEVELOPMENT ACTIVITY ATTN: ATZL-CAT-E ATZL-CAT-A FORT LEAVENWORTH KA 66027-5300	1 1	CDR NAVAL SEA SYSTEMS CMD ATTN: CODE 05M4 (MR R LAYNE) WASHINGTON DC 20362-5101	1
CDR US ARMY LOGISTICS CTR ATTN: ATCL-MS (MR A MARSHALL) ATCL-C FORT LEE VA 23801-6000	1 1	CDR DAVID TAYLOR NAVAL SHIP R&D CTR ATTN: CODE 2830 (MR BOSMAJIAN) CODE 2759 (MR STRUCKO) CODE 2831 ANNAPOLIS MD 21402	1 1 1
PROJECT MANAGER PETROLEUM & WATER LOGISTICS ATTN: AMCPM-PWL 4300 GOODFELLOW BLVD ST LOUIS MO 63120-1798	1	CG FLEET MARINE FORCE ATLANTIC ATTN: G4 (COL ROMMANTZ) NORFOLK VA 23511	1
CDR US ARMY ARMOR & ENGINEER BOARD ATTN: ATZK-AE-AR ATZK-AE-LT FORT KNOX KY 40121	1 1	CDR NAVAL SHIP ENGINEERING CENTER ATTN: CODE 6764 (MR. BOYLE) PHILADELPHIA PA 19112	1
		CDR NAVAL AIR SYSTEMS CMD ATTN: CODE 53545 (MR MEARNS) WASHINGTON DC 20361	1

PROJ MGR, M60 TANK DEVELOPMENT  
ATTN: USMC-LNO  
US ARMY TANK-AUTOMOTIVE  
COMMAND (TACOM)  
WARREN MI 48397

DEPARTMENT OF THE NAVY  
HQ, US MARINE CORPS  
ATTN: LPP (MAJ LANG)  
LMM/2 (MAJ PATTERSON)  
WASHINGTON DC 20380

CDR  
NAVAL AIR DEVELOPMENT CTR  
ATTN: CODE 60612  
WARMINSTER PA 18974

CDR  
NAVAL RESEARCH LABORATORY  
ATTN: CODE 6170  
CODE 6180  
CODE 6110 (DR HARVEY)  
WASHINGTON DC 20375

CDR  
NAVAL FACILITIES ENGR CTR  
ATTN: CODE 1202B (MR R BURRIS)  
200 STOVAL ST  
ALEXANDRIA VA 22322

COMMANDING GENERAL  
US MARINE CORPS DEVELOPMENT  
& EDUCATION COMMAND  
ATTN: DO74 (LTC WOODHEAD)  
QUANTICO VA 22134

CDR  
NAVAL AIR ENGR CENTER  
ATTN: CODE 92727  
LAKEHURST NJ 08733

OFFICE OF THE CHIEF OF NAVAL  
RESEARCH  
ATTN: OCNR-126 (MR ZIEM)  
CODE 432 (DR MILLER)  
ARLINGTON, VA 22217-5000

CDR  
NAVY PETROLEUM OFC  
ATTN: CODE 43 (MR LONG)  
CAMERON STATION  
ALEXANDRIA VA 22304-6180

CHIEF OF NAVAL OPERATIONS  
ATTN: OP 413  
WASHINGTON DC 20350

#### DEPARTMENT OF THE AIR FORCE

HQ, USAF  
ATTN: LEYSF (COL LEE)  
WASHINGTON DC 20330

HQ AIR FORCE SYSTEMS CMD  
ATTN: AFSC/DLF (MAJ VONEDA)  
ANDREWS AFB MD 20334

CDR  
US AIR FORCE WRIGHT AERONAUTICAL  
LAB  
ATTN: AFWAL/POSF (MR CHURCHILL)  
AFWAL/POSL (MR JONES)  
AFWAL/MLSE (MR MORRIS)  
AFWAL/MLBT (MR SNYDER)  
WRIGHT-PATTERSON AFB OH 45433

CDR  
SAN ANTONIO AIR LOGISTICS  
CTR  
ATTN: SAALC/SFT (MR MAKRIS)  
SAALC/MMPRR  
KELLY AIR FORCE BASE TX 78241

CDR  
HQ 3RD USAF  
ATTN: LGSF (CPT HEWITT)  
APO NEW YORK 09127

CDR  
WARNER ROBINS AIR LOGISTIC  
CTR  
ATTN: WRALC/MMTV (MR GRAHAM)  
ROBINS AFB GA 31098

CDR  
USAF 3902 TRANSPORTATION  
SQUADRON  
ATTN: LGTVP (MR VAUGHN)  
OFFUTT AIR FORCE BASE NE 68113

CDR  
DET 29  
ATTN: SA-ALC/SFM  
CAMERON STATION  
ALEXANDRIA VA 22314

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NATIONAL AERONAUTICS AND  
SPACE ADMINISTRATION  
VEHICLE SYSTEMS AND ALTERNATE  
FUELS PROJECT OFFICE  
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LEWIS RESEARCH CENTER  
CLEVELAND OH 44135

DEPARTMENT OF TRANSPORTATION  
FEDERAL AVIATION ADMINISTRATION  
ATTN: AWS-110 1  
800 INDEPENDENCE AVE, SW  
WASHINGTON DC 20590

US DEPARTMENT OF ENERGY  
CE-151  
ATTN: MR ECKLUND 1  
FORRESTAL BLDG.  
1000 INDEPENDENCE AVE, SW  
WASHINGTON DC 20585

ENVIRONMENTAL PROTECTION  
AGENCY  
AIR POLLUTION CONTROL 1  
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